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APPLICATION FOR LETTERS PATENT

**Method and Apparatus for Transmitting Data  
with Reduced Coupling Noise**

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1 **TECHNICAL FIELD**

2 The present invention relates to the transmission of data. More specifically,  
3 the present invention reduces coupling noise between conductors by using  
4 particular routing patterns for the conductors and/or modifying the coupling such  
5 that the transmitter coupling is approximately the same as the receiver coupling.  
6

7 **BACKGROUND**

8 Transmission lines often suffer from crosstalk which results from the  
9 parasitic coupling between nearby conductors. The coupling between the  
10 conductors can be either capacitive or inductive in nature and is typically  
11 associated with integrated circuit packages, connectors, and printed circuit traces  
12 positioned in parallel with one another.

13 A particular type of data transmission system transmits signals  
14 differentially along pairs of conductors. A differential driver receives data at an  
15 input and generates a corresponding differential signal on a pair of outputs (i.e., an  
16 inverting output and a non-inverting output). The differential signal is transmitted  
17 across a pair of conductors and received by a differential receiver, which rejects  
18 signals that are present on both conductors (referred to as common mode signals).  
19 This differential transmission system helps reduce noise that is induced on both  
20 conductors, however coupling noise still exists on the conductors. For example, a  
21 differential pair of conductors is likely to have noise when passing through a  
22 connector. As transmission rates increase, the resulting increase in signal edge  
23 rates will aggravate this problem.  
24

25 Existing techniques to reduce coupling between conductors include adding

1 ground conductors between signal conductors or positioning the signal conductors  
2 farther away from one another. However, the addition of ground conductors  
3 between signal conductors increases the number of conductors, thereby increasing  
4 the cost and complexity of the system. Further, if the conductors are traces on a  
5 printed circuit board, the addition of ground conductors between signal conductors  
6 increases the printed circuit board area required to route all of the conductors.  
7 Positioning the signal conductors farther away from one another increases the size  
8 of the printed circuit board, connector, integrated circuit package, or other device  
9 that handles the conductors.

10 Fig. 1 illustrates a prior art system in which inductive coupling occurs  
11 between various conductors. The system uses differential signaling to transmit  
12 three bits of data across three differential line pairs. The inductors shown coupled  
13 in series with the various conductors represent the inductances inherent in the  
14 conductors. The three data bits are designated as a, -a, b, -b, c, and -c. An  
15 integrated circuit 100 receives or generates the three data bits that are provided to  
16 differential drivers 108, 110, and 112. The signals generated by the differential  
17 drivers 108-112 are transmitted through a connector 102, another connector 104,  
18 to another integrated circuit 106. Each of the three pairs of conductors is coupled  
19 to one of three differential receivers 114, 116, or 118, which are contained in  
20 integrated circuit 106. For example, the system shown in Fig. 1 may be a  
21 backplane having the connectors 102 and 104 mounted to the backplane. In this  
22 example, integrated circuits 100 and 106 are mounted on a substrate (such as a  
23 printed circuit board) which is electrically coupled to one of the connectors 102,  
24 104.  
25

1 In the example of Fig. 1, coupling noise is caused by inductive coupling.  
2 This coupling corresponds to parasitic mutual inductance which occurs due to the  
3 physical construction of the integrated circuit packages and connectors in the  
4 system. In Fig. 1, the mutual inductance is represented by inductive coupling  
5 coefficient K1, K2, and K3. Since the two connectors 102 and 104 are the same,  
6 they have the same inductive coupling coefficient (K2). The two integrated circuit  
7 packages 100 and 106 are different, so they each have a different inductive  
8 coupling coefficient (K1 and K3).

9 The signal quality in the system of Fig. 1 is degraded due to the parasitic  
10 mutual inductance. For example, if signals a, -a and c, -c switch while signals  
11 b, -b are quiet, a noise signal will appear at the receiver end of the line carrying b,  
12 -b. This type of noise signal reduces the timing and voltage margins of data  
13 arriving at the differential receiver 114, 116 or 118.

14 The system and method described herein addresses these and other  
15 problems by reducing the coupling noise on conductors positioned near one  
16 another.

## 17 SUMMARY

18  
19 In one embodiment, a first device is coupled to a first connector. A second  
20 connector is coupled to the first connector through multiple conductors, in which  
21 alternating pairs of conductors are reversed. A second device is coupled to the  
22 second connector through a second group of multiple conductors.

23 In another embodiment, the first device includes multiple differential  
24 drivers to transmit differential signals.  
25

1 In a particular implementation of the system, the second device includes  
2 multiple differential receivers to receive multiple differential signals.

3 Another embodiment provides that the inductive coupling of the first device  
4 is substantially the same as the inductive coupling of the second device.

5 In a particular embodiment, alternating pairs of conductors in the second  
6 group of multiple conductors are reversed.

7 In a described implementation, a transmitter package is modified such that  
8 the coupling coefficient of the transmitter package is substantially the same as the  
9 coupling coefficient of a receiver package. Multiple pairs of differential signals  
10 are transmitted using the transmitter package. The receiver then receives and  
11 decodes the multiple pairs of differential signals.  
12

### 13 **BRIEF DESCRIPTION OF THE DRAWINGS**

14 Fig. 1 illustrates a prior art system in which inductive coupling occurs  
15 between various conductors.  
16

17 Fig. 2 illustrates an embodiment of a system that reduces coupling noise.

18 Fig. 3 illustrates a pair of connectors coupled together with multiple pairs  
19 of transmission lines.

20 Fig. 4 is a flow diagram illustrating a procedure for reducing coupling noise  
21 between conductors.

22 Fig. 5 illustrates another embodiment of a system that reduces coupling  
23 noise between conductors.

24 Fig. 6 is a flow diagram illustrating another procedure for reducing  
25 coupling noise between conductors.

1  
2 **DETAILED DESCRIPTION**

3 The method and apparatus for transmitting data with reduced coupling  
4 noise (both inductive coupling and capacitive coupling) described herein routes  
5 the signal conductors in a particular manner to reduce the inductive coupling  
6 between signal conductors. Additionally, the transmitter coupling is modified to  
7 be approximately the same as the receiver coupling to reduce the inductive  
8 coupling between signal conductors. Particular examples herein are described  
9 with reference to integrated circuits and connectors. However, the teachings of the  
10 present invention can be applied to any type of device coupled to any type of  
11 interconnection mechanism.

12 Fig. 2 illustrates an embodiment of a system that reduces inductive  
13 coupling noise. An integrated circuit 200 receives or generates three data bits  
14 (labeled a, -a, b, -b, c, and -c), and contains three differential drivers 208, 210, and  
15 212. Each of the three pairs of signal conductors is coupled to one of the three  
16 differential drivers. Differential drivers 208-212 may also be referred to as  
17 differential transmitters. The integrated circuit 200 can be any type of integrated  
18 circuit such as a memory device, a processor, an ASIC, or programmable logic  
19 devices. The signal conductors used to transmit data may include wires, cables,  
20 traces on a printed circuit board, conductors embedded within a substrate (e.g.,  
21 between different layers of a substrate), and various other conductive materials.

22 The signals generated by the differential drivers 208-212 are transmitted  
23 through a connector 202, another connector 204, to another integrated circuit 206.  
24 Integrated circuit 206 contains three differential receivers 214, 216, and 218, each  
25 coupled to receive a different pair of signal conductors. Differential receivers 214-

1 218 may also be referred to as differential decoders. The connectors 202 and 204  
2 can be any type of electrical connecting device capable of coupling with at least  
3 one component, such as a mating connector, a substrate, an edge of a printed  
4 circuit board, etc.

5 In a particular embodiment, the system of Fig. 2 is a backplane having  
6 multiple connectors (e.g., connectors 202 and 204) electrically coupled to the  
7 backplane. The backplane is a printed circuit board, which can be manufactured  
8 using any type of substrate capable of supporting the multiple connectors and  
9 multiple conductors that interconnect the multiple connectors. The backplane may  
10 be a multi-level board having multiple layers of substrate materials and/or  
11 conductive materials. In this embodiment, the integrated circuits 200 and 206 are  
12 mounted on another substrate (e.g., a printed circuit board or "card") that is  
13 electrically coupled to the corresponding connector 202 or 204. In a particular  
14 configuration, integrated circuits 200 and 206 are memory devices (either volatile  
15 or non-volatile memory devices), each of which is mounted on a printed circuit  
16 board. The memory device and printed circuit board combination may be referred  
17 to as a memory module. Any number of memory modules can be electrically  
18 coupled to connectors mounted to a backplane.

19 As shown in Fig. 2, the two outer differential pairs (i.e., a, -a and c, -c)  
20 have a polarity reversal (also referred to as a "twist" or a conductor reversal)  
21 between the two connectors 202 and 204. This polarity reversal significantly  
22 reduces (or eliminates) the coupling noise of the two connectors 202 and 204  
23 because any coupling noise added by connector 202 is subtracted by connector  
24 204. The polarity is reversed again between connector 204 and integrated circuit  
25

1 206. This second polarity reversal ensures that the differential receiver receives  
2 the inverted and non-inverted signals on the appropriate input pins.

3 In an alternate embodiment, the second polarity reversal is not necessary  
4 because the polarity of the input connections to the differential receiver is  
5 reversed. For example, in the orientation shown in Fig. 2, without the second  
6 polarity reversal, the "a" signal (non-inverted) would be coupled to the inverted  
7 input to the differential receiver 214 and the "-a" signal (inverted) would be  
8 coupled to the non-inverted input to the differential receiver 214. However, if the  
9 orientation of the differential receiver 214 is reversed such that the positions of the  
10 inputs to the differential receiver are reversed, then the second polarity reversal of  
11 the signal conductors is not necessary.

12 Fig. 3 illustrates a pair of connectors 230 and 232 coupled together with  
13 multiple pairs of conductors. As shown in Fig. 3, alternating pairs of conductors  
14 have reversed polarity. As discussed above, this reversed polarity significantly  
15 reduces (or eliminates) the coupling noise induced by the two connectors  
16 because any coupling noise added by one connector is subtracted by the other  
17 connector. The top pair of conductors 234 and 236 have their polarity reversed.  
18 The next pair of conductors 238 and 240 are not reversed. The next pair of  
19 conductors have a reversed polarity, and the next pair is not reversed. This pattern  
20 of reversing the polarity of alternating pairs of conductors continues until the last  
21 pair of conductors. In the example of Fig. 3, seven pairs of conductors are  
22 illustrated. However, the teachings of the present invention can be applied to  
23 systems having any number of pairs of conductors coupled between two  
24 connectors.  
25



1        Additionally, in the example of Fig. 3, the polarity reversals are shown  
 2 approximately midway between the two connectors 230 and 232. However, in  
 3 alternate embodiments, the polarity reversals may be located anywhere between  
 4 the two connectors 230 and 232. Further, the polarity reversals need not occur at  
 5 the same location. For example, a first polarity reversal may occur close to  
 6 connector 230, a second polarity reversal may occur midway between the two  
 7 connectors 230 and 232, and a third polarity reversal may occur close to the  
 8 connector 232.

9        Fig. 4 is a flow diagram illustrating a procedure for reducing coupling noise  
 10 between conductors. First, an integrated circuit generates multiple pairs of  
 11 differential signals (block 250). A first connector generates inductive coupling  
 12 noise as the differential signals are transmitted through the first connector (block  
 13 252). Next, the procedure reverses the polarity of alternating pairs of differential  
 14 signal conductors (block 254). A second connector generates inductive coupling  
 15 noise opposite the noise generated by the first connector as the differential signals  
 16 are transmitted through the second connector (block 256). The procedure then  
 17 reverses the polarity of alternating pairs of differential signal conductors (block  
 18 258). The pairs of signal conductors reversed in block 258 are the same as those  
 19 reversed in block 254. Finally, the procedure decodes the multiple pairs of  
 20 differential signals.

21        Fig. 5 illustrates another embodiment of a system that reduces coupling  
 22 noise between conductors. The system illustrated in Fig. 5 is similar to the system  
 23 illustrated in Fig. 2. An integrated circuit 300 includes three differential drivers  
 24 308, 310, and 312. Integrated circuit 300 may also be referred to as the transmitter  
 25 package because it transmits the signals. The signals generated by the differential

1 drivers 308-312 are transmitted through a connector 302, another connector 304,  
2 to another integrated circuit 306, which includes three differential receivers 314,  
3 316, and 318. Integrated circuit 306 may also be referred to as the receiver  
4 package because it receives the signals from the transmitter package (i.e.,  
5 integrated circuit 300).

6 In the embodiment of Fig. 5, the polarity of alternating pairs of conductors  
7 (i.e., a, -a and c, -c) is reversed between the two connectors 302 and 304.  
8 However, there is no corresponding polarity reversal between connector 304 and  
9 integrated circuit 306, as shown in Fig. 2. Also, the inductive coupling between  
10 conductors in integrated circuit 300 is K3, which is the same inductive coupling as  
11 in integrated circuit 306. In this embodiment, the inductive coupling noise caused  
12 by the two connectors 302 and 304 is significantly reduced due to the polarity  
13 reversal in the conductors, as discussed above. Further, the inductive coupling  
14 noise caused by the two integrated circuits 300 and 306 is reduced because the two  
15 integrated circuits have substantially the same inductive coupling coefficient.

16 The system shown in Fig. 5 is designed to provide symmetric coupling  
17 between the two halves of the transmission lines (i.e., integrated circuit 300 and  
18 connector 302 represent one half, and connector 304 and integrated circuit 306  
19 represent the other half. The symmetry between the two connectors 302 and 304  
20 is provided by the polarity reversal between the two connectors. Similarly, the  
21 symmetry between the two integrated circuits 300 and 306 is provided by the same  
22 coupling in the two integrated circuits.

23 In a particular system, the receiver package (i.e., integrated circuit 306) has  
24 more coupling than the transmitter package (i.e., integrated circuit 300). To  
25 provide the necessary symmetry, the coupling of the transmitter package is

1 increased (i.e., more coupling noise is generated) to match the coupling of the  
2 receiver package. The coupling coefficient of the transmitter package can be  
3 increased by redesigning the package of the integrated circuit so that the coupling  
4 coefficient of the transmitter package is substantially similar to the coupling  
5 coefficient of the receiver package. For example, in a typical integrated circuit  
6 package, crosstalk results from the inductive coupling between bond wires. The  
7 inductive coupling is proportional to the length of the bond wires, in which longer  
8 bond wires have greater inductive coupling. Thus, the coupling coefficient of the  
9 transmitter package can be increased by increasing the bond wire length.

10 As shown in Fig. 5, the polarity of the conductors is not reversed between  
11 connector 304 and integrated circuit 306 (as was the case in Fig. 2). However, the  
12 orientation of the differential receivers 314 and 318 is reversed such that the  
13 inverted signal (-a and -c) is coupled to the inverted input of the differential  
14 receiver and the non-inverted signal (a and c) is coupled to the non-inverted input  
15 of the differential receiver. Note that the orientation of differential receiver 316 is  
16 not reversed because the associated pair of conductors were not reversed between  
17 the two connectors 302 and 304.

18 In an alternative embodiment, the orientation of differential receivers 314  
19 and 318 is not changed. Thus, the inverted signals are coupled to the non-inverted  
20 inputs and the non-inverted signals are coupled to the inverted inputs. Thus, the  
21 differential receivers 314 and 318 generate incorrect outputs (i.e., the opposite of  
22 the actual value). This is easily corrected by coupling an inverter to the output of  
23 each differential receiver 314 and 318. The output of the inverter is the correct  
24 output for the system.  
25

1 In another embodiment, two integrated circuits (e.g., integrated circuits 300  
2 and 306) are coupled to one another through multiple pairs of conductors (i.e., a  
3 chip-to-chip link). As mentioned above, the inductive coupling coefficient of the  
4 first integrated circuit is designed to be substantially the same as the inductive  
5 coupling coefficient of the second integrated circuit. In this embodiment, no  
6 connectors are located between the two integrated circuits. This configuration  
7 provides for the reversing of polarities on alternating line pairs, in the manner  
8 discussed. Thus, instead of reversing polarities of signal lines between two  
9 connectors, this configuration reverses the polarity of signal lines coupled between  
10 the two integrated circuits.

11 Fig. 6 is a flow diagram illustrating another procedure for reducing  
12 coupling noise between conductors. The flow diagram shown in Fig. 6  
13 corresponds to the system shown in Fig. 5. First, the transmitter package is  
14 modified such that the coupling coefficient of the transmitter package is  
15 substantially the same as the receiver package (block 350). The transmitter  
16 package generates multiple pairs of differential signals (block 352). A first  
17 connector generates inductive coupling noise as the differential signals are  
18 transmitted through the first connector (block 354). Next, the procedure reverses  
19 the polarity of alternating pairs of differential signal conductors (block 356). A  
20 second connector generates inductive coupling noise opposite to the noise  
21 generated by the first connector as the differential signals are transmitted through  
22 the second connector (block 358). Finally, the procedure decodes the multiple  
23 pairs of differential signals (block 360).

24 Thus, a system has been described that reduces inductive coupling noise  
25 between conductors. The noise reduction is accomplished by reversing alternating

1 pairs of conductors and/or modifying the coupling of the integrated circuit  
2 packages such that the transmitter coupling is substantially the same as the  
3 receiver coupling.

4 Although the description above uses language that is specific to structural  
5 features and/or methodological acts, it is to be understood that the invention  
6 defined in the appended claims is not limited to the specific features or acts  
7 described. Rather, the specific features and acts are disclosed as exemplary forms  
8 of implementing the invention.

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